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ABSTRACT

The NASA Dryden Flight Research Facility performs ground vibration testing to assess the structural characteristics of new and modified research vehicles. This paper updates the research activities, techniques used, and experiences in applying this technology to aircraft since 1987. Test equipment, data analysis methods, and test procedures used for typical test programs are discussed. The data presented illustrate the use of modal test and analysis in flight research programs for a variety of aircraft. This includes a technique to acquire control surface free-play measurements on the X-31 airplane more efficiently, and to assess the effects of structural modifications on the modal characteristics of an F-18 aircraft. In addition, the status and results from current research activities are presented. These data show the effectiveness of the discrete modal filter as a preprocessor to uncouple response measurements into simple single-degree-of-freedom responses, a database for the comparison of different excitation methods on a JetStar airplane, and the effect of heating on modal frequency and damping.

NOMENCLATURE

DFRF	Dryden Flight Research Facility, Edwards, CA
FEM	finite element model
GVT	ground vibration test
HARV	High Alpha Research Vehicle
LVDT	linear variable differential transformer
MIMO	multiple-input–multiple-output
NASA	National Aeronautics and Space Administration
PC	personal computer
SDOF	single degree of freedom
SISO	single-input–single-output
UC - SDRL	University of Cincinnati - Structural Dynamic Research Laboratory, Cincinnati, OH

INTRODUCTION

The National Aeronautics and Space Administration's (NASA) Dryden Flight Research Facility (DFRF) continually conducts flight research using a mix of new airframes and modified fleet aircraft. Since aircraft are flexible, they are prone to a variety of aeroelastic instabilities ranging from mere nuisances to abrupt and catastrophic structural failures. Each proposed research program is evaluated to determine the potential for encountering such instabilities in flight. The measures used to ensure the prevention of these instabilities include predictive stability analyses[1] ground vibration tests (GVT),[2] open- and closed- loop flight control system tests,[3] and flight flutter tests.[4]

A GVT measures the modal characteristics of a structure. This information is used to assess the significance of structural modifications, verify or update the analytical models used in flutter analyses, plan flight flutter tests, and interpret flight test results.

Research into improving and expanding the role of GVTs is required to support these flight test programs properly as advances are made in flight technology. New materials, exotic configurations, thermal effects from aerodynamic heating, and advanced flight control systems can have significant effects on the in-flight aeroelastic stability of these aircraft.

The purpose of this paper is to update the GVT paper published in 1987.[2] Since that time, new equipment has been obtained, test techniques have been updated, and additional GVTs have been conducted. Current test techniques and lessons learned from recent tests are also presented in this paper. Also discussed are current research activities in modal testing at elevated temperatures and efforts directed toward developing automated test techniques.

TEST EQUIPMENT

A variety of equipment is required to conduct a GVT. The amount and type of equipment and the scope of the test itself depend on the size of the vehicle or article being tested and the desired results. The equipment used at the DFRF is representative of equipment required to conduct vibration tests on fighter-size vehicles or smaller.

SHAKERS

Electrodynamic shakers are the primary method of exciting an aircraft structure. The DFRF has a total of 14 shakers. The specifications of these shakers can be found in reference 2. Each shaker is attached to the aircraft by a telescoping thrust rod and a stinger.[5] A force transducer is mounted atop the stinger and is attached to a locking swivel assembly, which is typically bolted or bonded directly to the structure.

Vacuum cups have also been used to attach shakers. These devices are used on control surfaces and composite structures where no means of direct attachment exist. A vacuum pump is required to maintain the vacuum within the cup.

In addition to the shakers, impact hammers are available for use primarily with component tests such as plates or avionic equipment racks.

INSTRUMENTATION

The majority of aircraft modal tests conducted at the DFRF use light weight (3 gram), high-sensitivity (1 volt per g), low-cost accelerometers. The magnitude limitation of these accelerometers is 10 gs and the frequency range is from 1 to 1000 Hz. The DFRF has approximately 300 of these transducers so that an entire aircraft can be completely instrumented for any given test. The high sensitivity is ideal for obtaining good signal-to-noise ratios even when the response amplitudes are low.

In addition, smaller quantities of other accelerometers are available for applications that exceed the operational limitations of the low-cost accelerometers. These include general-purpose and high-temperature accelerometers.

Some testing requires velocity or displacement measurements. For this purpose laser vibrometers and linear variable differential transformers (LVDT) are also available for use.

Vibration testing is also supported by instrumentation hardware such as oscilloscopes, voltmeters, strip charts, amplifiers, and filters. These devices are also part of the GVT facility and the majority are rack-mounted on wheeled carts (Fig. 1). Thus, the equipment can be transported as needed to the test site(s), providing a significant amount of flexibility.

COMPUTERS

The DFRF uses commercially available, modular data acquisition hardware, supported by workstation-based software. The workstation is shown in Figure 2. The current configuration has been upgraded from 8 input channels[2] to 200 input channels of simultaneous data acquisition. The current system also has six programmable signal generators. In addition, since the hardware is modular, up to three smaller tests can be conducted simultaneously. To help support these smaller tests, a 386 and a 486 personal computer (PC) are used for data acquisition and analyses in a manner similar to the workstation (Fig. 3).

SOFT SUPPORT SYSTEMS

Soft support systems are used to approximate free-free (unconstrained) boundary conditions by reducing the frequency of the six rigid-body support modes as much as possible. At the DFRF, these support systems include an overhead airbag[2], under-the-gear airbags[2], and a jack point pendulum-supported pneumatic spring system.

The pendulum-supported pneumatic spring system consists of three jack point support units (Fig. 4). Each unit has a pressurized air cylinder that is supported by three rods, which forms the pendulum. This arrangement attaches at each aircraft jack point and allows movement in all six rigid-body degrees of freedom. The vertical plunge frequency of the air cylinder–pendulum arrangement is approximately 0.8 Hz while the other degree-of-freedom frequencies are 0.5 Hz. It is important that the support rigid-body frequencies are low so that there is sufficient separation between the rigid-body modes and the elastic modes on the airplane. This system requires that the airplane be hoisted for mounting onto the units.

Some tests, where the soft support is not required or practical, are conducted with the vehicle's landing gear resting directly on the floor. In this configuration, the landing gear struts are deflated to reduce potential nonlinear oscillations, and the tire pressure is reduced to one-half normal to provide a soft support. This approach is used with considerable caution because the rigid-body landing gear modes may be inadequately isolated from the flexible-body dynamic modes.

EXCITATION TECHNIQUES

Most aircraft tests conducted at the DFRF excite the structure with multiple shakers, initially using random or burst random excitation. The advantages and disadvantages of using this type of signal are well documented in reference 6.

Often, there are tests in which the random excitation technique does not provide adequate excitation for all the modes of interest. In these cases, slow sine sweep or sine-dwell techniques are used. It has been found through experience that no single method of excitation is superior for every test application.

Impact excitation[7] is generally used for small structures or aircraft components. It provides an effective approach when low-excitation input energy is needed.

MODAL PARAMETER ESTIMATION

The DFRF maintains several commercial software packages to extract modal parameters from measured data. These packages provide many ways to estimate modal parameters, from single-input–single-output (SISO), single-degree-of-freedom (SDOF) techniques to multiple-input–multiple-output (MIMO), multiple-degree-of-freedom (MDOF) techniques.[6] The approach typically taken is to first perform quick-look SISO pole estimation during the test using the mode indicator function[8] as a guide. The MIMO estimation routines are usually used post-test when a complete analysis of the data is performed.

Unfortunately, none of the algorithms work well enough to be used with confidence in all cases and none provide uncertainty bands with the parameter estimates. This drawback will most likely become a critical issue in the future.[9]

TEST PROCEDURES

The following section discusses typical measures taken to prepare the aircraft for a GVT.

The aircraft must be structurally complete with all structural load bearing doors and covers installed and secured. It may be necessary to remove some nonstructural panels to provide access for external hydraulic lines and electrical power. All structural panel fasteners should be properly torqued. Loose fasteners or components rattling during the test can contaminate the response data, and it is worth the effort to minimize this source of error.

Major aircraft components should either be present on the aircraft, or properly mass represented and secured to the aircraft. One needs to exercise a certain amount of judgment in this area. One kilogram (2.2 lb) of mass missing on a control surface is critical while 10 kg (22 lb) of mass missing near the center of gravity in the fuselage may not be critical.

Control surface free play must be removed to increase the linearity of the measured data.[2] The typical procedure is to preload the surfaces with heavy weights (25 kg (55 lb)) suspended from elastic cord taped to the control surface edge. The plunge frequency of the weight should be less than 1 Hz, so that the weight's influence on the elastic modes is minimal.

The amount of fuel in each tank is determined so that the test configuration represents the analytical configuration as closely as possible. Special precautions must be taken with volatile fuels to reduce vapors that could ignite in the test area. The fuel system can be purged and filled with an inert fluid which has similar mass properties to reduce the hazards.

The aircraft hydraulic and flight control systems must be functional. These two systems work together in modern aircraft to provide the capability of positioning the control surfaces in a trimmed position for the test. In addition, the hydraulic system provides stiffness for the control surface rotation modes. The flight control system must be able to open the sensor feedback loops so that there is no control surface motion commanded during the test. Most modern flight control systems provide such a mode.

The boundary conditions are important especially if the data are to be used to verify and update analytical models. In this case a free-free (unconstrained) condition is required which dictates the use of a soft support system. The soft support system ideally should separate the rigid body and elastic modes by a factor of 10 or more. However, tests have been conducted where these modes have been separated by a factor of four and excellent modal test results have been achieved.

Tests are often conducted to determine the frequency of a structure or to determine the effects of a structural modification on the modal frequency by conducting a test before and after the modification. In these cases, a sufficient soft support can be obtained with the aircraft resting on the landing gear.

Shaker placement is critical for proper excitation of modes. Modes of interest will not be excited when shakers are placed at their respective node lines. Typical shaker locations, such as wingtip, could actually be at the node lines for some of the higher frequency modes. Vibration analysis results can be a helpful guide in this case.

Once the aircraft is in the test configuration, an initial set of measurements is made. Typically, burst random excitation is used to excite the structure at the DFRF. The driving point frequency response function is measured first to determine that the structure has been excited reasonably well over the frequency range of interest and to be certain that the hardware is operating properly.

Sometimes all of the expected modes do not respond properly over the desired frequency range. In this case, additional shakers can be added (or moved) or a different type of excitation, such as sine-dwell, can be tried. This is also a good time to perform any nonlinearity and reciprocity checks.[6]

Once the test setup and data quality are satisfactory, the remainder of the test consists of acquiring the data. Large data acquisition systems allow for data acquisition in a short amount of time.

EXAMPLE GROUND TESTS

F-18 Harv Airplane

The F-18 High Alpha Research Vehicle (HARV)[10] is a preproduction F-18 that has been significantly modified to conduct flight research at high angles of attack. Recent modifications included the addition of thrust vectoring vanes about the exhaust of each engine, a spin chute assembly to the aft section of the airplane, and emergency system batteries and ballast to the forward section of the fuselage. The total weight added to the fuselage was approximately 1364 kg (3000 lb).

An extensive GVT was conducted to determine the effects of these modifications on the modal characteristics of the airplane and to acquire data to update the finite element model (FEM) used in the aeroelastic and aeroservoelastic analyses. The airplane was mounted on the airspring–pendulum soft support system (Fig. 5) and the response of the airplane was measured at 193 points.

The results of the test with a full fuel loading are presented in table 1. These test results are compared with unmodified F-18 airplane GVT results, and the preliminary and final F-18 HARV vibration analysis results. The data show that the modal characteristics were significantly affected by the modification. The results of the preliminary vibration analysis compare well with the test results with the exception of the antisymmetric wing bending mode. This mode participated in the antisymmetric wing flutter mechanism and had to be accurately modeled if one were to have confidence in the flutter analysis results.

The stiffness of the wing fold mechanism was modeled as a spring in the FEM. Decreasing the stiffness of this spring produced the results in the final vibration analysis shown in table 1. These results now agree closely with the experimentally measured values.

The F-18 HARV program is an example of how a GVT is used to qualify an airplane for flight. The GVT determines the change in the modal characteristics caused by structural modifications. The test results were used to update the FEM to more accurately represent the airplane. Consequently, flutter analysis results with higher confidence were produced and this had the effect of reducing the number of flight flutter test points in the program.

X-31 Thrust Vectored Airplane

The X-31 (Fig. 6) is a single-engine experimental airplane with 17 control surfaces including 3 thrust vectoring vanes about the exhaust of the engine. The amount of control surface free play and its effect on the aeroelastic stability was a concern for this airplane. Stringent free-play tolerances were specified and measurements were made every 100 flight hours.

Modal test equipment was used to measure the free play of the airplane's flight control surfaces in a quasi-static fashion. The technique involves oscillating a control surface with electrodynamic shakers at a frequency of 1 Hz. This frequency was selected as being low enough to avoid inertial effects but high enough to avoid leakage effects associated with the control surface actuator by-pass orifices. Each control surface was oscillated through its free-play region and into a region where the control surface displacement varied linearly with input force. The surface displacement was measured with a linear variable differential transformer (LVDT). The shakers and the LVDT were mounted to the aircraft structure by means of vacuum cups. This mounting method provided for quick setups and relocation of the test equipment. The overall setup is shown in Figure 7.

A personal computer (PC) was used to acquire the shaker force and LVDT signals. These signals were plotted against each other to form a Lissajous figure. A typical Lissajous figure is shown in Figure 8. Lines were faired through the linear portions of the loaded and unloaded segments. The value of free play was measured as the vertical distance between these lines at the origin of the Lissajous figure. Hysteresis and actuator stiffness could also be obtained from this figure if desired.

This method, which used modal test equipment, provided a quick and accurate means of measuring control surface free play of an aircraft. This method was considered an improvement over the traditional static method.

RESEARCH ACTIVITIES

Hot Structures Vibration Testing

Flight vehicles that fly at hypersonic speeds are subjected to high surface temperatures and large temperature gradients. These conditions affect the modal characteristics of the structure and can seriously affect the aeroelastic and aeroservoelastic stability of the vehicle. If FEM analysis methods are to be relied upon to predict these instabilities, then accurate determination of the effect of heat on the modal characteristics of these structures is vital.

A series of heated structure vibration tests has been conducted on aluminum, titanium, and fiberglass plates at uniform, nonuniform, and transient heating profiles.[11,12] Each plate was 30.5 cm (12 in.) wide, 127 cm (50 in.) long, and typically 0.51 cm (0.2 in.) thick. A typical test setup is shown in Figure 9. This program was conducted to research the experimental test technique required for heated structures and to establish an initial database for analysis code verification.

Figure 10 shows a comparison of the frequency response function of an aluminum plate at room temperature and heated to 204 °C (400 °F). In general, it has been found that modal frequency and amplitude decreased and the damping increased as temperature was increased. Predictive vibration analyses have been performed on each plate tested and good correlation has been obtained with the experimental data.[13] One finding of this research was that more development of experimental test methods and analytical procedures are required for composite materials. There are plans to continue the research in the experimental and analytical areas for composite structures.

On-Line Modal State Monitor

A joint research program to develop on-line parameter estimation schemes for nonstationary linear systems is being conducted with the University of Cincinnati - Structural Dynamics Research Laboratory (UC - SDRL).[14,15] This concept uses the discrete modal filter. The modal filter is simply a coordinate transformation from physical to modal coordinates. In modal coordinates, the response of the structure is viewed as a combination of independent single-degree-of-freedom oscillators. Expressing the response of the structure in this fashion makes it easier to understand the dynamics of the vibrating system.

To illustrate the usefulness of a modal filter, it was applied to a damped, six-mode analytical system. Figure 11 shows the response trace containing the six modes in physical coordinates and the decoupled response of the first three modes after applying the modal filter. This results is a single-degree-of-freedom trace for each mode.

A test was conducted on a truss structure (Fig. 12) to show how the modal state monitor using the modal filter might be used. Data were acquired at 23 response points on this structure. The on-line monitor was used to observe the structure for 128 sec. At 30 sec, the structure was modified by abruptly fixing a corner of the structure to the ground. At 60 sec, the corner of the structure was abruptly released which returned the structure to its original state. The results for one mode of the structure are shown in Figure 13. The monitor, using a simple recursive least-squares estimation algorithm, detected these changes and was converging on the new results. Although the convergence speed of this recursive least-square algorithm was not sufficient for tracking the change of this system in an on-line fashion, it does show the viability of this approach for implementing an on-line procedure. The modal filter is considered to be a promising data condensation technique leading to more robust estimates and automated testing techniques.

Jetstar Ground Vibration Test Airplane

The DFRF has decommissioned a modified JetStar airplane and has retained it as a structural dynamics test article. The airplane (Fig. 14) is structurally complete and provides a realistic test article on which to experiment and develop new GVT techniques.

A database has been established with this airplane to compare different excitation methods. These methods include sine dwell, single and multiple input random, and impulsive sine.[2,16,17] Table 2 compares frequency and damping values for each type of excitation. In general, the frequency values compared well and the damping values showed a fair comparison. Variations in the estimated damping values may be caused by data scatter or may be a result of using different estimation algorithms for each type of excitation.[16,17]

This airplane will continue to be used as a test article for verification and development of new test techniques.

CONCLUDING REMARKS

The Dryden Flight Research Facility has upgraded its ground vibration test system from 8 to 200 data acquisition channels. The current hardware configuration is modular and can be divided into three smaller systems which allows vibration tests to be conducted simultaneously. This equipment upgrade has improved data quality and larger amounts of data can now be acquired in less time.

The modal parameter estimation techniques have been maintained to the state-of-the-art level available from commercial software packages. Current techniques provide many ways to estimate modal parameters, from single-input–single-output systems to multiple-input–multiple-output systems. Each technique has advantages and disadvantages and no one technique is solely relied upon for all testing.

Ground vibration testing continues to fulfill a vital role in assuring the absence of aeroelastic instabilities of new and modified research aircraft. Test data are used to assess the significance of structural modifications, verify or update the analytical models used in flutter analyses, plan flight flutter tests, and interpret flight test results. Research into improving and expanding the role of ground vibration testing is on going at the Dryden Flight Research Facility to support the flight test programs of the future properly.

REFERENCES

1. Bisplinghoff, Raymond L., Holt Ashley, and Robert L. Halfman, "Aeroelasticity," Addison-Wesley Publishing Company, Reading, MA, 1962.

2. Kehoe, Michael W., *Aircraft Ground Vibration Testing At The NASA Ames-Dryden Flight Research Facility Research Facility*, NASA TM-88272, 1987.

3. Peloubet, R.P., Jr., R.L. Haller, C.N. McComb, and R.M. Bolding, "Ground Vibration Testing Of Fighter Aircraft With Active Control Systems," AFFDL-TR-76-110, Vol. 1–4, 1976.

4. *Flutter Testing Techniques*, NASA SP-415, 1975.

5. Ewins, D.J., "Modal Testing: Theory and Practice," John Wiley and Sons Inc., 1984.

6. Allemang, Randall J. and David L. Brown, "Experimental Modal Analysis and Dynamic Component Synthesis," Air Force Wright Aeronautical Laboratories Report AFWAL-TR-87-3069, Vol. 1–6, Dec. 1987.

7. Halvorsen, William G. and David L. Brown, "Impulse Technique for Structural Frequency Response Testing," *Sound and Vibration*, Nov. 1987, pp. 8–21.

8. Williams, Roger, John Crowley, and Håvard Vold, "The Multivariate Mode Indicator Function in Modal Analysis," Third International Modal Analysis Conference, Jan. 1985.

9. Allemang, Randall J., "Modal Analysis -- Where Do We Go From Here?", 11th International Modal Analysis Conference, Kissimmee, FL, 1993.

10. Regenie, Victoria A., Donald H. Gatlin, Robert Kempel, and Neil W. Matheny, *The F-18 High Alpha Research Vehicle: A High-Angle-Of-Attack Testbed Aircraft*, NASA TM-104253, 1992.

11. Kehoe, Michael W. and H. Todd Snyder, *Thermoelastic Vibration Test Techniques,* NASA TM-101742, 1991.

12. Snyder, H. Todd and Michael W. Kehoe, *Determination of the Effects of Heating on Modal Characteristics of an Aluminum Plate With Application to Hypersonic Vehicles*, NASA TM-4274, 1991.

13. Kehoe, Michael W. and Vivian C. Deaton, *Correlation of Analytical and Experimental Hot Structure Vibration Results*, NASA TM-104269, 1993.

14. Shelley, S.J., L.C. Freudinger, and R.J. Allemang, "Development of an On-Line Parameter Estimation System Using the Discrete Modal Filter," 10th International Modal Analysis Conference, San Diego, CA, Feb. 1992.

15. Shelley, Stuart J., Lawrence C. Freudinger, and Randall J. Allemang, "Development of an On-Line Modal State Monitor," 11th International Modal Analysis Conference, Kissimmee, FL, Feb. 1993.

16. Kehoe, Michael W., F.W. Cazier, Jr., and Joseph F. Ellison, *Ground Vibration Test of the Laminar Flow Control JetStar Airplane*, NASA TM- 86398, 1985.

17. Kehoe, Michael W. and David F. Voracek, *Ground Vibration Test Results of a JetStar Airplane Using Impulsive Sine Excitation*, NASA TM-100448, 1989.

Table 1. Correlation of F-18 experimental and analytical vibration results.

Mode description	Frequency, Hz			
	Unmodified F-18 GVT	F-18 HARV GVT	Preliminary analysis	Final analysis
Symmetric wing bending	5.94	6.02	5.98	5.71
Fuselage lateral bending	8.22	6.64	6.86	6.86
Fuselage vertical bending	9.57	7.76	7.49	7.44
Antisymmetric wing bending	8.78	8.33	9.21	8.44
Symmetric wing torsion	13.81	11.80	12.42	11.61
Antisymmetric wing torsion	12.29	12.13	12.68	12.01
Antisymmetric stabilizer bending	13.59	13.45	13.30	13.54
Symmetric stabilizer bending	---	13.63	13.13	13.68
Wing fore/aft, vertical stabilizer bending	---	15.09	15.01	14.98
Fuselage 2nd vertical bending	---	15.23	15.94	15.17
Antisymmetric vertical stabilizer bending	---	15.31	16.40	15.52
Symmetric vertical stabilizer bending	---	15.68	16.85	15.92
2nd wing bending	16.11	17.00	17.97	16.94
Fuselage torsion	---	22.00	19.20	18.69

Table 2. Modal parameter comparison for a modified JetStar airplane.

Mode description	Sine dwell		Single point random	
	Frequency, Hz	Damping, G	Frequency, Hz	Damping, G
Symmetric wing bending	4.90	0.018	4.92	0.020
Empennage roll, fuselage torsion	5.05	0.026	5.20	0.014
Empennage roll, engine pylon bending	5.75	0.026	5.97	0.014
Engine pylon bending/stabilizer bending	7.49	0.016	7.57	0.017
Symmetric stabilizer and fuselage vertical bending	9.18	0.014	9.27	0.012
Antisymmetric wing bending	10.86	0.037	10.79	0.034
Symmetric stabilizer, fuselage vertical bending and engine pylon pitch	11.05	0.075	11.25	0.032
Antisymmetric wing bending and engine pylon pitch	13.88	0.016	13.92	0.012
Symmetric 2nd wing bending and engine pylon pitch	16.12	0.059	16.32	0.075

Mode description	Multiple input random		Impulsive sine	
	Frequency, Hz	Damping, G	Frequency, Hz	Damping, G
Symmetric wing bending	4.92	0.011	4.94	0.021
Empennage roll, fuselage torsion	5.13	0.019	5.20	0.012
Empennage roll, engine pylon bending	5.87	0.017	5.95	0.014
Engine pylon bending/stabilizer bending	7.93	0.020	7.49	0.016
Symmetric stabilizer and fuselage vertical bending	9.14	0.024	9.22	0.013
Antisymmetric wing bending	10.47	0.032	10.64	0.018
Symmetric stabilizer, fuselage vertical bending and engine pylon pitch	10.96	0.052	10.96	0.024
Antisymmetric wing bending and engine pylon pitch	13.55	0.026	13.65	0.014
Symmetric 2nd wing bending and engine pylon pitch	16.22	0.056	16.22	0.088

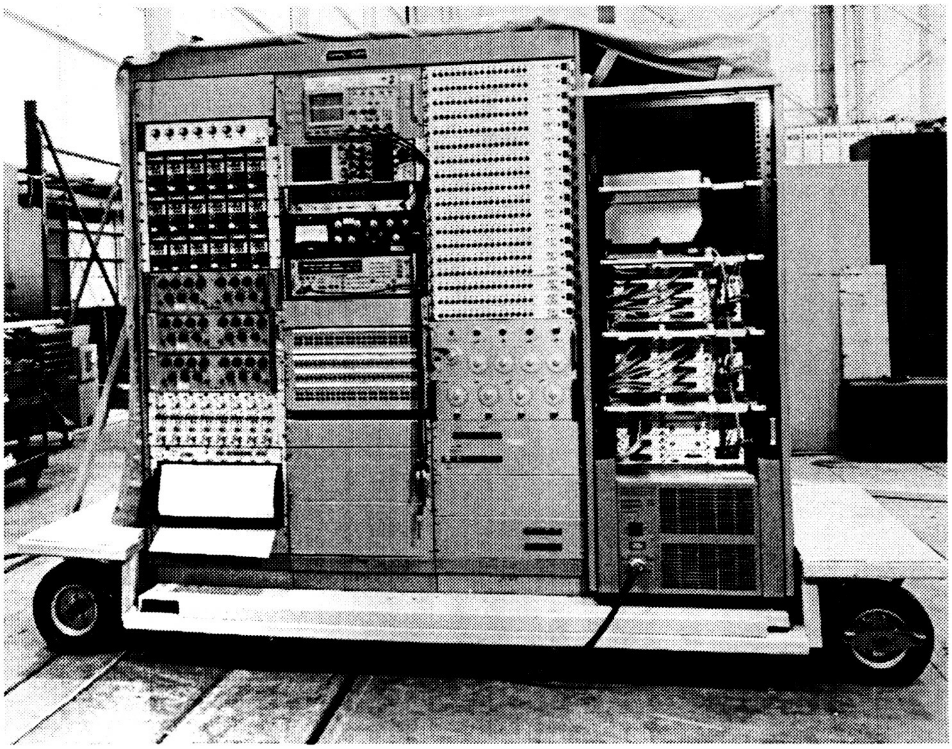

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Figure 1. Rack-mounted instrumentation cart.

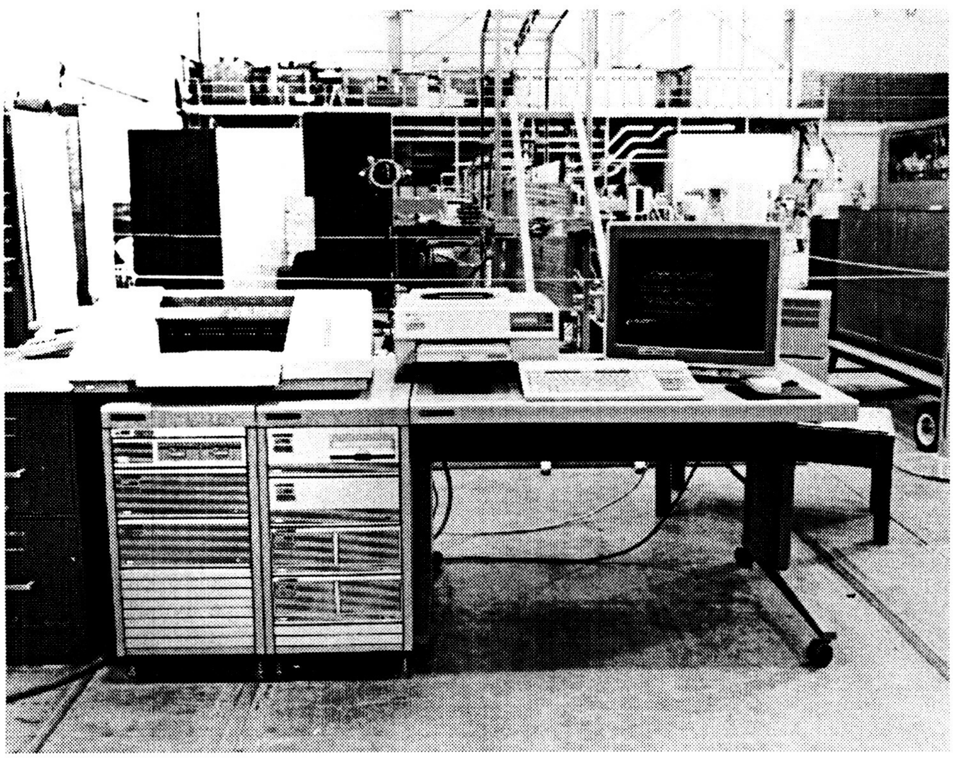

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Figure 2. Modal analysis workstation.

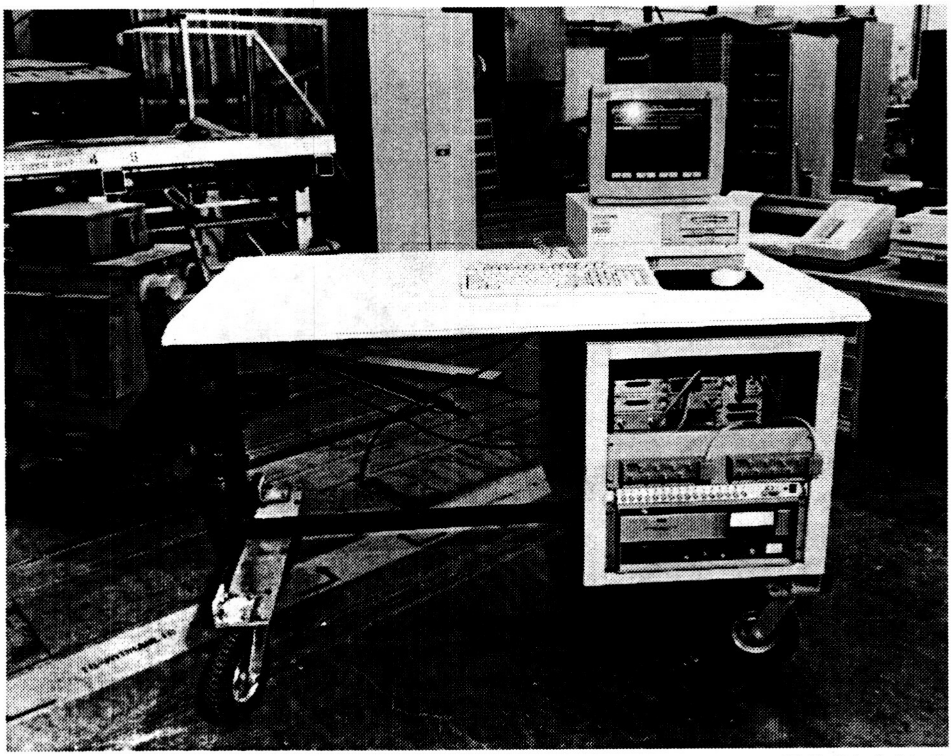

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Figure 3. Personal computer based data acquisition system.

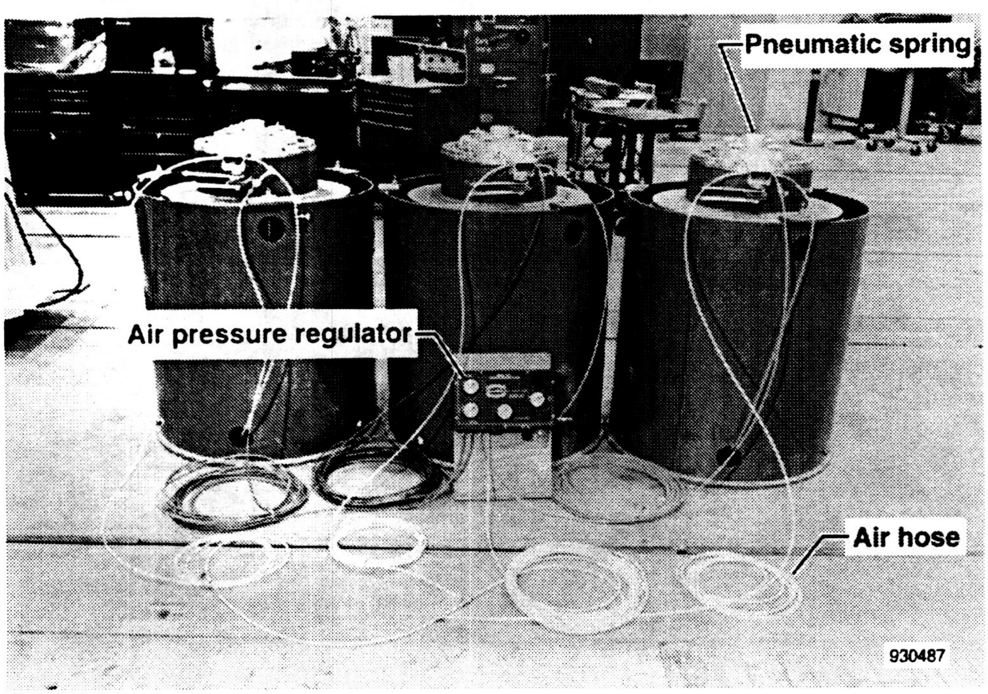

Figure 4. Pendulum-supported pneumatic spring soft support system.

Figure 5. F-18 HARV airplane mounted on the pneumatic spring soft support system.

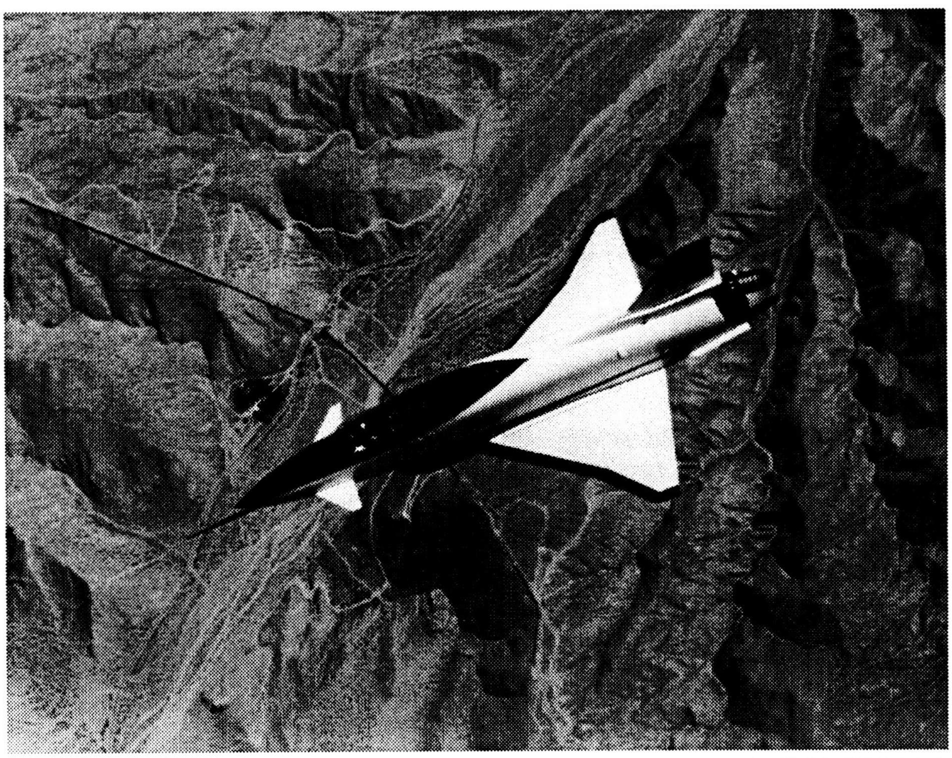

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Figure 6. X-31 airplane.

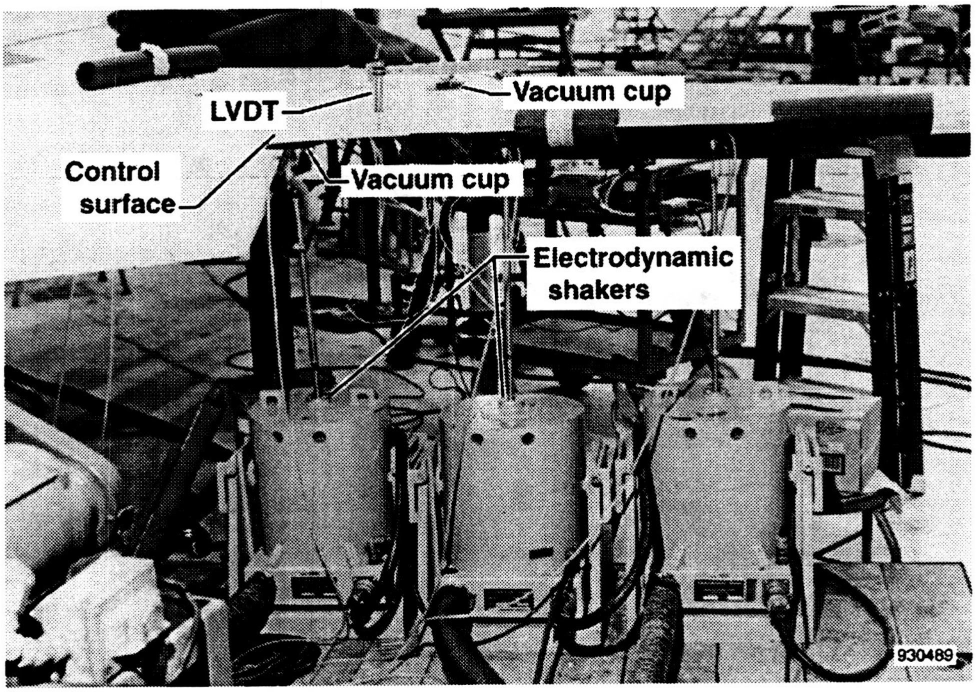

Figure 7. X-31 control surface free play test setup.

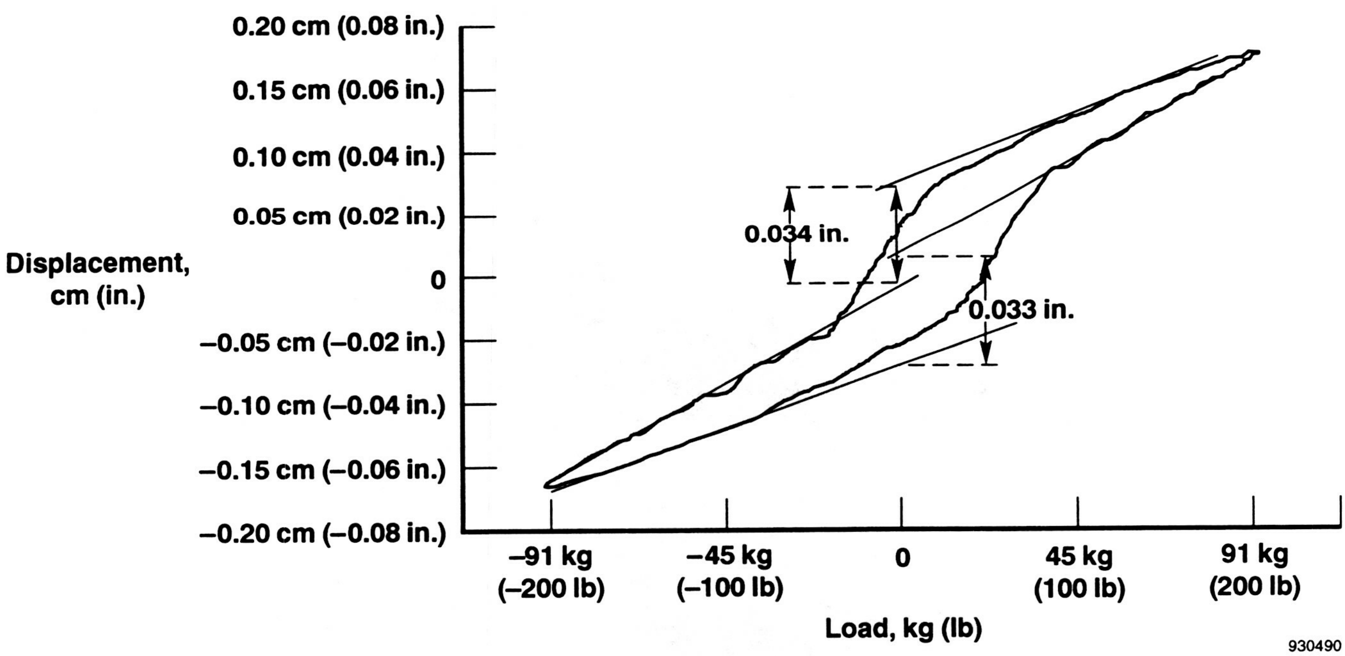

Figure 8. Typical Lissajous figure depicting free play on a control surface.

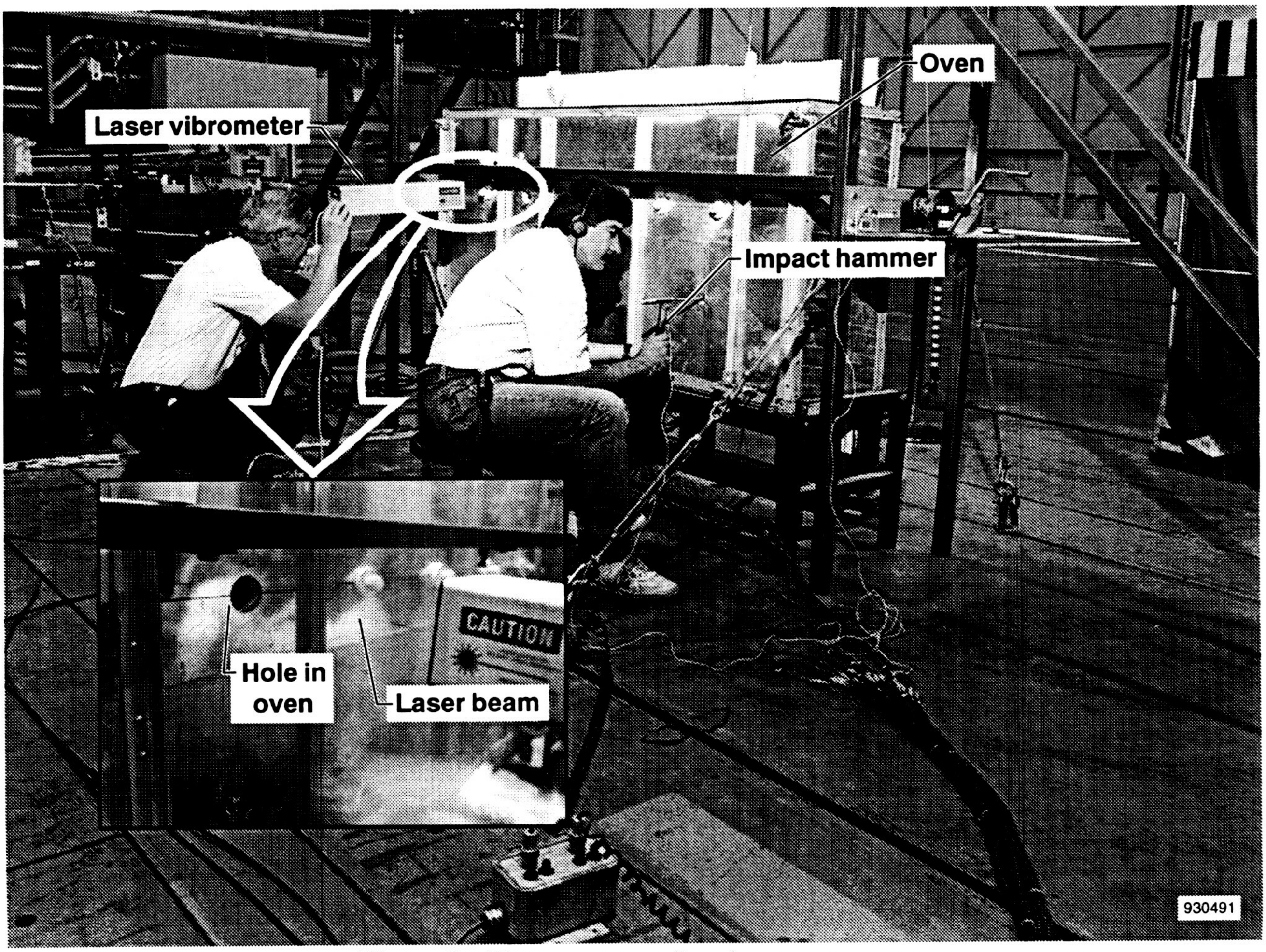

Figure 9. Hot structure vibration test setup.

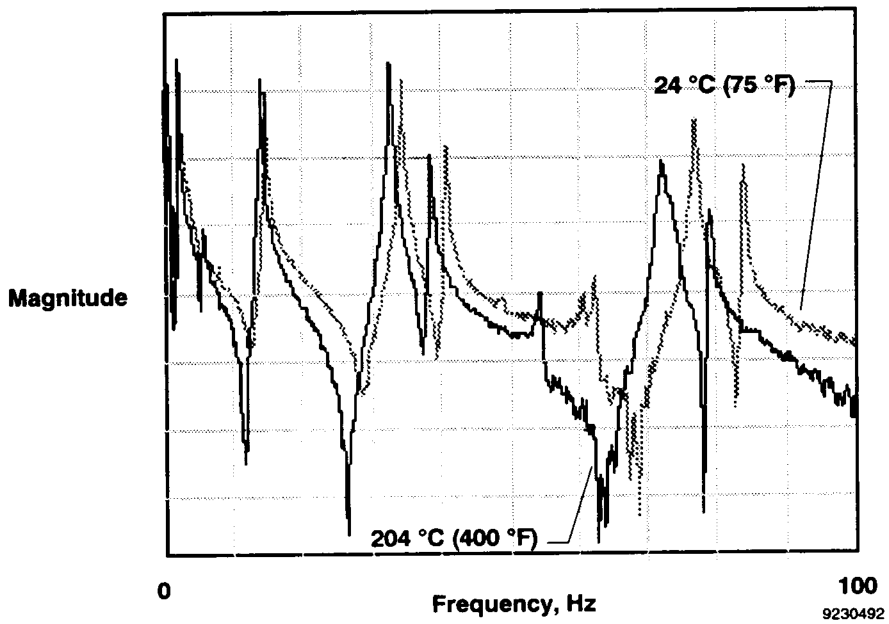

Figure 10. Comparison of frequency response plots obtained at room and elevated temperature.

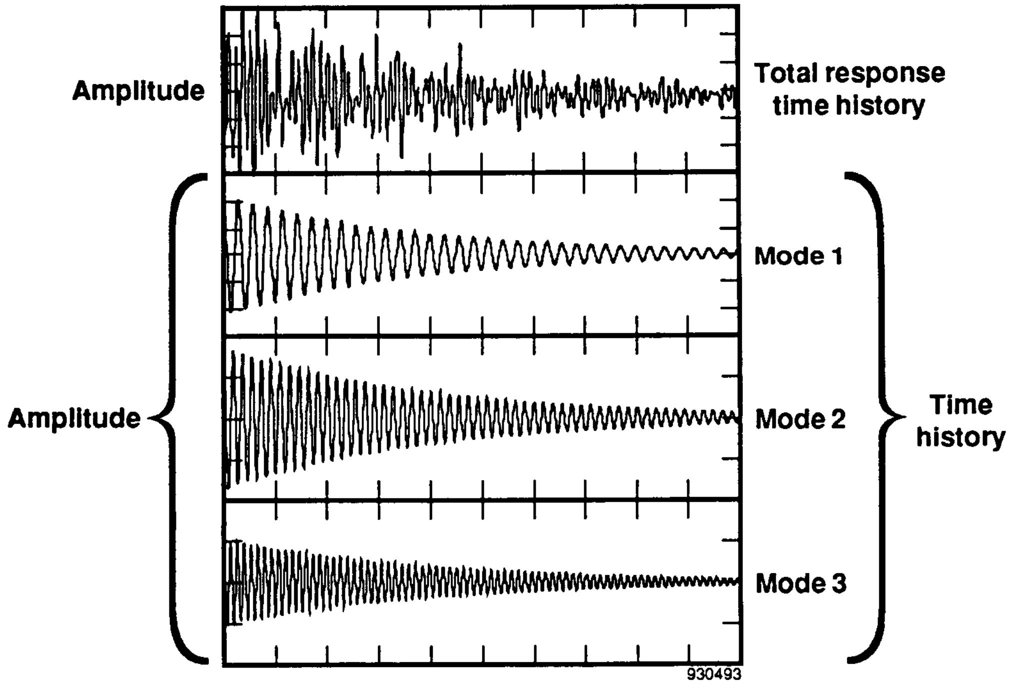

Figure 11. Unfiltered and modally filtered time histories.

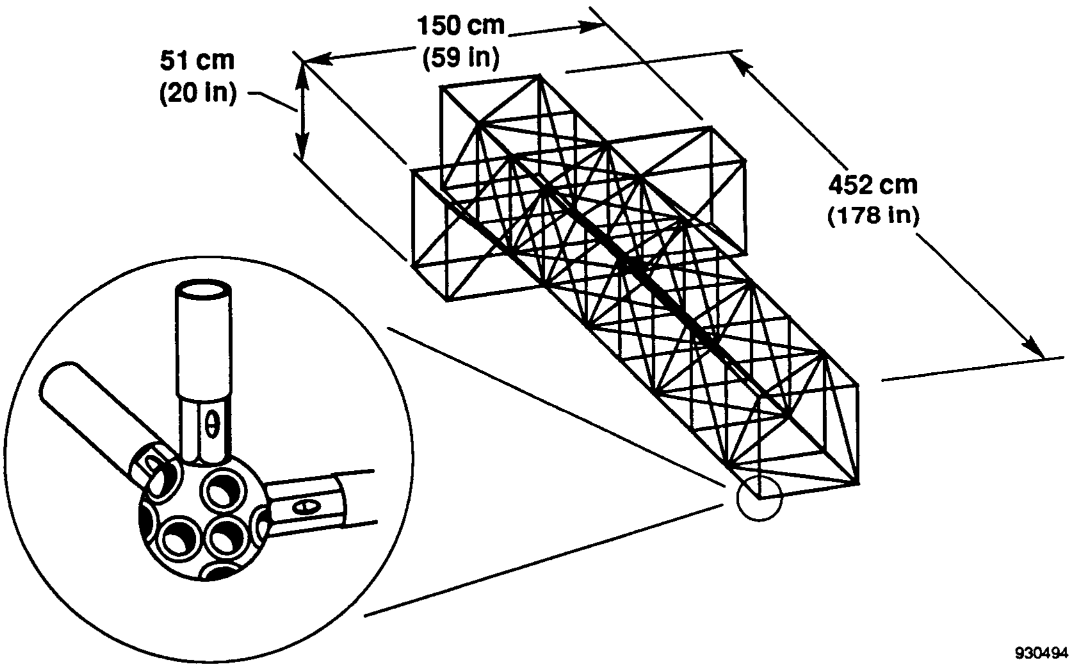

Figure 12. Truss structure assembly.

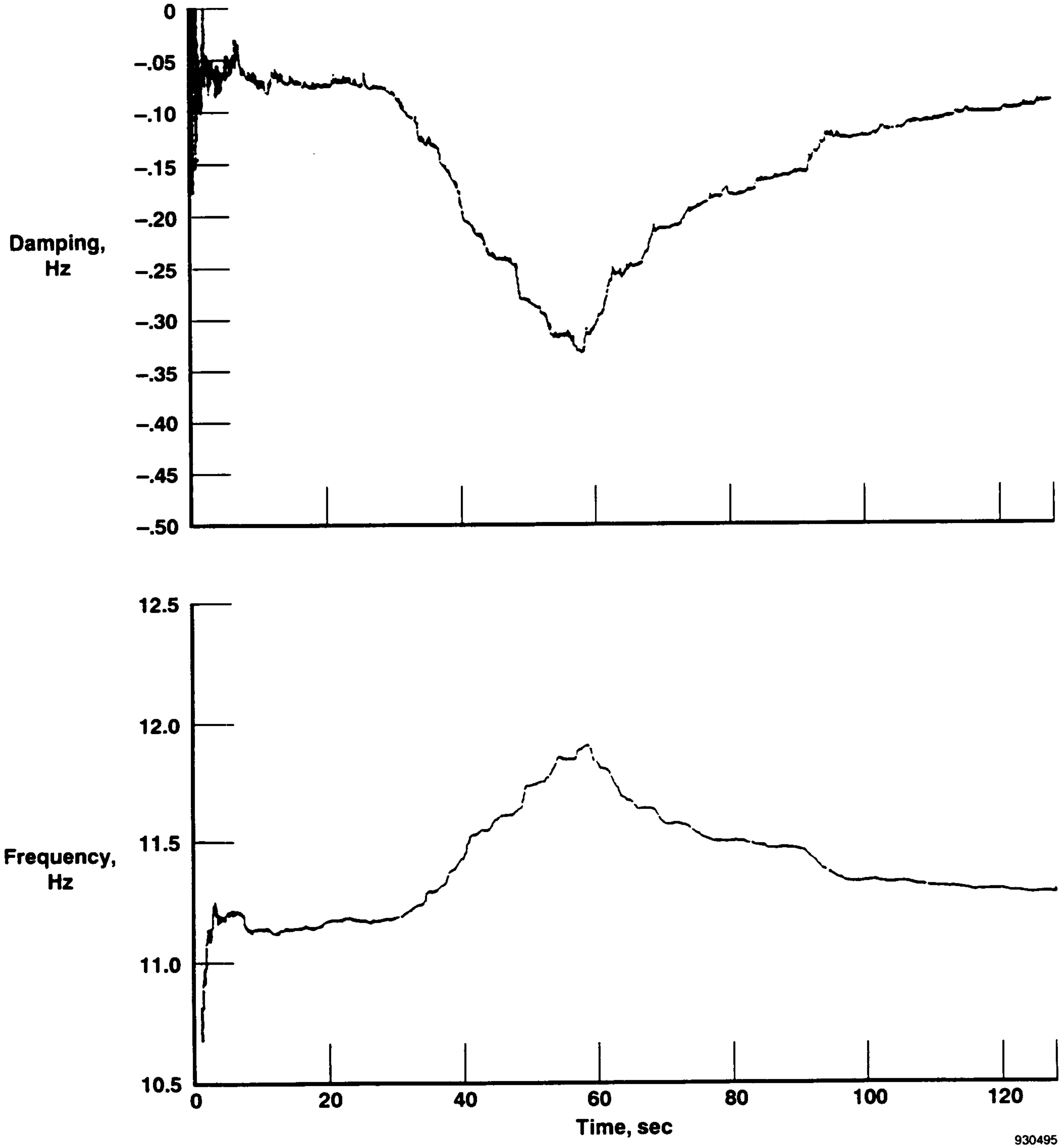

Figure 13. Frequency and damping estimates for one mode of a nonstationary system.

Figure 14. JetStar airplane.

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13. ABSTRACT (Maximum 200 words)

The NASA Dryden Flight Research Facility performs ground vibration testing to assess the structural characteristics of new and modified research vehicles. This paper updates the research activities, techniques used, and experiences in applying this technology to aircraft since 1987. Test equipment, data analysis methods, and test procedures used for typical test programs are discussed. The data presented illustrate the use of modal test and analysis in flight research programs for a variety of aircraft. This includes a technique to acquire control surface free-play measurements on the X-31 airplane more efficiently, and to assess the effects of structural modifications on the modal characteristics of an F-18 aircraft. In addition, the status and results from current research activities are presented. These data show the effectiveness of the discrete modal filter as a preprocessor to uncouple response measurements into simple single-degree-of-freedom responses, a database for the comparison of different excitation methods on a JetStar airplane, and the effect of heating on modal frequency and damping.

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